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# Primary Stratigraphic Traps in Sandstones[1]

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**Abstract** Primary stratigraphic traps in sandstone involve lateral termination of the reservoir as a direct or indirect result of factors related to the depositional environment. Red Wash, Coalinga East, Pembina, Mitsue, Bell Creek, Cut Bank, Burbank, and Bradford are among the very few giant oil accumulations found in such traps. As these traps rarely can be detected by surface measurements, other discovery methods are essential. The understanding of depositional process and environment is a promising approach.

Primary stratigraphic traps in sandstone are present in many facies, including fluvial, deltaic, shallow marine, and deeper marine. The largest sizes and greatest number occur in shallow-marine and shoreline environments. Knowledge of sandstone models of all kinds may provide valuable clues in interpreting fragmentary well data in terms of size, shape, trend, and characteristics of the reservoirs being sought.

The distribution of many sandstone bodies may be controlled in part by underlying, commonly inconspicuous, erosional surfaces. Reconstruction of the paleotopography of the unconformity thus may commonly delineate prospective trends. The distribution of trap barriers may be controlled by environment. For example, discrete shoreline sandstone bodies replaced updip by lagoonal shales are better prospects than those replaced updip by sandy ("leaky") deltaic deposits. Such sandstones are more likely to be related to interdeltaic rather than deltaic areas.

Most progress will come from further development and refinement of depositional models. A greater understanding of shallow-marine sandstone bodies is especially needed. Moreover, as exploration emphasis shifts offshore, there will be a growing premium on ability to recognize depositional models in the absence of cores and outcrops.

## Introduction

Oil-filled stratigraphic traps in sandstone are hard to find. Most known ones were found either unintentionally in the course of exploration for structural accumulations or through intensive drilling programs based on scarce subsurface leads. Yet, the presence of large traps like those at the Burbank and Pembina fields and the decreasing number of economically attractive onshore structural prospects have spurred great research efforts over the past 15 years to develop techniques for finding stratigraphic traps with only a minimum of subsurface control. Although some of this research has been aimed at empirical correlations and some at development of geophysical and geochemical approaches sensitive to lateral variations of thin stratigraphic units, the emphasis has been on environmental types of sandstone bodies. Each environmental type has a characteristic size, geometry, paleogeographic orientation, and relation to enclosing facies; it also has characteristic internal porosity and permeability distributions. As we learn to distinguish each type in cores, cuttings, and logs, we can explore more effectively for oil and gas. Better knowledge of the nature of the target allows more effective design of the appropriate set of exploration approaches and techniques, thus enhancing exploration success.

A knowledge of depositional models has been applied to exploration at the prospect level and, particularly, to efficient field development and extension.

Equally important is the regional delineation of favorable areas. On this scale of stratigraphic-trap exploration, depositional environment of sandstones is only one of many relevant geologic factors in fairway delineation; others include structural history, postdepositional alteration, adequacy of source rocks, *etc.*

## Principal Findings

Primary stratigraphic traps in sandstone-shale sequences are commonly present in alluvial, deltaic, and shallow-marine deposits and are less common in deep-water sandstones. They are especially common in the Pennsylvanian of the Mid-Continent and the Cretaceous of the Rocky Mountains, but are scarce in the Tertiary of California and the Gulf Coast. Major oil accumulations in primary stratigraphic

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Marathon's work in the interpretation of sandstones has been concentrated heavily in the Cretaceous of the Rocky Mountains, partly because of outstanding surface exposures and available subsurface cores, and partly because of Marathon's historic exploration interest there. Consequently, many of the examples in this paper are drawn from the Rocky Mountain Cretaceous. However, the sandstone depositional models and exploration approaches discussed should be broadly applicable. Only for deep-water sandstones does one have to seek elsewhere for appropriate models.

In preparing this paper, I have drawn on the work of my Marathon colleagues both in exploration and in research, particularly that of J. C. Harms and D. G. McCubbin. I acknowledge with thanks their contributions and comments.

Critical reviews by H. R. Gould, G. Rittenhouse, and W. K. Stenzel led to significant improvements in the paper.

traps in sandstone are scarce compared to those in structural, reef, and unconformity-sealed traps.

Individual primary stratigraphic-trap prospects cannot be defined by any combination of present surface geophysical or geochemical methods, except that large traps in thick sandstone bodies less than 3,000 ft (915 m) deep possibly are detectable by gravity or seismic methods. The principal reason is that primary stratigraphic traps occur at the lateral edges of sandstone bodies usually less than 100 ft (30 m) thick. Even if lateral variations in porosity or saturation in such thin genetic units could be detected from the surface, they would be obscured by other unrelated changes in shallower and deeper rocks.

On the basis of subsurface information, lateral proximity to stratigraphic traps may be indicated by lateral changes in clay content, formation-water salinity, or hydrodynamic gradient. Highs related to inferred differential-compaction effects in beds overlying a discontinuous sandstone body may encourage deeper drilling to reach it. However, since such proximity indicators are rare—and successful use is even more rare—a more general approach is needed. A review of data from wildcat failures in light of knowledge of many different kinds of sandstone depositional models is still a very useful guide to finding traps.

For delineation of the more prospective fairways, reconstruction of the paleogeography has been one successful technique. It probably should be augmented more commonly by considerations of postdepositional processes such as solution, cementation, clay-mineral dehydration, and fluid-potential gradients.

Many primary traps are present in sandstones whose distribution is partly or wholly controlled by an underlying erosional surface. Examples include alluvial-valley and marine strike-valley fills (Fig. 6). In view of this relation, paleotopographic and paleogeologic maps of the erosional surfaces are important aids to exploration for many primary stratigraphic traps. Even where an erosional surface is not a factor or cannot be identified, shoreline sandstones deposited during an overall transgression may be more prospective than those deposited during an overall regression (Fig. 5).

In future exploration, our growing knowledge of stratigraphy, including both depositional and diagenetic aspects of rock interpretation, will have important application in delineating prospective fairways in which to concentrate effort on finding structural and pre-unconformity traps, as well as primary stratigraphic traps.

## Primary Traps

In the stratigraphic traps in sandstone discussed in this paper, lateral variation in the lithology of the reservoir rock, or a break in its continuity, has been a major factor in entrapment. In most of them, the lateral variation of permeability is a direct result of the depositional environment, rather than of postdepositional selective solution or cementation. In those unusual and still poorly understood examples in which selective solution of fossil debris or less stable detrital grains has played a significant role in creating the reservoir, the selective solution itself probably is governed by factors related to the depositional environment. For these reasons, I shall refer to all of them as primary stratigraphic traps.

Following this definition, I exclude from consideration all those pools trapped beneath an angular unconformity, because the main trapping mechanism is unrelated to deposition of the reservoir sands. The East Texas field, with 6 billion bbl of ultimately recoverable oil in the Upper Cretaceous, is the best example in this category. A related group which is not considered includes those pools in which a tar seal at a surface unconformity is an important trapping element. Among the largest examples are the Bolívar Coastal field (Venezuela), with 30 billion bbl in the mid-Tertiary, and the Quiriquire field (Venezuela), with 1 billion bbl in the Pliocene-Pleistocene; the Kern River field of California, with 700 million bbl in the Pliocene-Pleistocene; and the Athabasca tar sands of northeastern Alberta. Fields such as these may be relatively easy to find, either because of surface seeps or because of convergence along unconformities detectable by the reflection seismograph.

Not only are primary stratigraphic traps harder to find, but giant fields in such traps are much more scarce. A few giant fields in this category are shown in Table 1.

## Trap Requirements

Reservoir rocks capable of containing significant amounts of oil must be juxtaposed with barrier beds capable of acting as effective seals in a three-dimensional configuration that encloses a volume of rock of low energy potential. This trap must form at the right time and place to intercept migrating oil. In a primary

**Table 1. Selected Giant Primary Sandstone Stratigraphic Traps**

| *Name* | *Location* | *Depth (ft)* | *Age* | *Year of Discovery* | *Ultimate Recoverable Reserves (million bbl)* | *Depositional Type* | *References* |
|---|---|---|---|---|---|---|---|
| Greater Red Wash | Utah | 5500 | Eocene | 1951 | 135[1] | Lacustrine delta | Koesoemadinata (1970) |
| Coalinga East | Calif. | 8000 | Eocene | 1938 | 520[1] | Shallow marine (?) | Chambers (1943) |
| Pembina | Alta. | 5000 | L. Cret. | 1953 | 1800[2] | Shallow marine | Michaelis (1957) and Nielson (1957) |
| Bell Creek | Mont. | 4500 | E. Cret. | 1967 | 114[1] | Barrier bar and Delta front<br>Barrier bar | McGregor and Biggs (1968)<br>Berg and Davies (1968) |
| Cut Bank | Mont. | 3000 | E. Cret. | 1926 | 200[1] | Alluvial valley | Blixt (1941), Shelton (1967) |
| Burbank | Okla. | 3000 | Penn. | 1920 | 500[1] | Shoreline<br>Alluvial valley | Bass *et al.* (1942)<br>Marathon (unpub.) and D. R. Baker (personal commun., 1969) |
| Bradford (partly structural) | Pa. | 1500 | L. Dev. | 1871 | 660[1] | Shallow marine<br>Turbidite | Fettke (1938)<br>(by comparison with nearby N. Y. Devonian outcrop) |
| Mitsue | Alta. | 5700 | M. Dev. | 1964 | 300[3] | Deltaic | Kramers and Lerbekmo (1967) |
| Nipisi | Alta. | 5500 | M. Dev. | 1965 | 200[3] | Deltaic (?) | Kramers and Lerbekmo (1967) |

[1] Oil and Gas Journal, January 26, 1970.
[2] Oil and Gas Journal, January 13, 1969.
[3] H. W. Nelson (personal commun., 1970).

stratigraphic trap, the boundary between the reservoir and the enclosing rocks may be slightly older than, contemporaneous with, or slightly younger than the reservoir itself.

Except for isolated lenses of sandstone enveloped in shale, most primary stratigraphic traps in sandstone have some structural elements; the configuration of the trap boundary is commonly governed by tilting or gentle arching as well as by stratigraphic variation. All gradations and combinations of structural and stratigraphic conditions have been observed.

Although the updip lateral change commonly is from reservoir sandstone to impermeable shale, the lithologic contrast need not be so great. In an area of western Nebraska, for example, the updip barrier to an alluvial valley-fill sandstone reservoir is itself a fine-grained sandstone with some permeability (Harms, 1966). The key is not contrast in permeability but rather in capillary-pressure characteristics.

One of the most difficult problems is how to predict the capacity of an updip stratigraphic-trap barrier. The problem arises because barriers commonly consist of complexly interlaminated sandstones, siltstones, and shales. In Figure 1, the block in the upper diagram represents a sandstone bed (overlain and underlain by shale beds not shown) dipping to the left. Oil is trapped downdip from the barrier. The lower diagram is a schematic representation of the same block, in which the innumerable tortuous channelways through the barrier are represented by three tubes.

The capacity of the barrier is determined by the "critical throat," the tightest part of the particular channelway that requires the least pressure for passage of oil through it. We have no way of sampling, measuring, or even estimating reliably the capacity of the throat; however, a minimum value possibly might be established by observation of the length of oil column in a nearby similar trap (Harms, 1966).

If hydrodynamic conditions prevail, the situation may be modified somewhat. If the hydrodynamic gradient is downdip, the capacity of the barrier to hold oil or gas is enhanced; if the gradient is updip, the barrier capacity is diminished correspondingly. In this way, local hydrodynamic conditions may influence the occurrence of stratigraphic traps or the size of the stratigraphic pools.

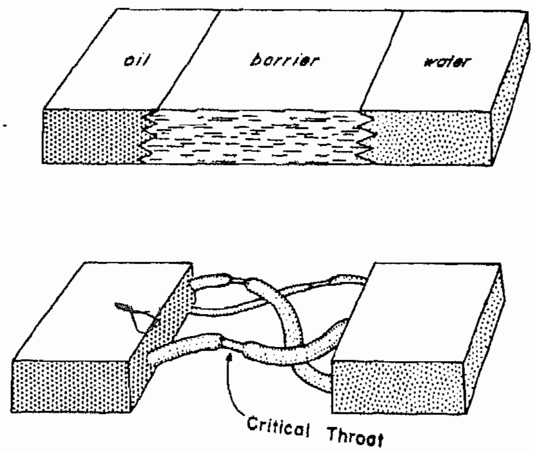


FIG. 1—Schematic diagram of stratigraphic-trap barrier.

Examples of fields with unusually effective stratigraphic-trap barriers—as indicated by the height of continuous oil column in the trap—are Horseshoe Canyon, northwest New Mexico (oil column 2,750+ ft, capillary pressure ~500 psi; McCubbin, 1969), and Coalinga East, California (1,800 ft, ~180 psi).

### Locating Prospects

Potter (1967) discussed prediction problems related to sandstone bodies. He considered two aspects: (1) "the location problem"—where to find the sandstone bodies—and (2) "the extension problem"—how to outline efficiently the areal extent with a minimum of drilling. Location of sandstone bodies at the prospect level and, more partciularly, location of traps are the primary concern in this section.

In relatively mature areas of known stratigraphic traps in sandstone, a common, and sometimes effective, exploration approach has been used for many years. This approach involves drilling on a structural nose between a downdip well with porous and permeable, but water-saturated, sandstone and an updip well with no reservoir sandstone. It was applied successfully in the 1950s in the Denver basin. Of course, where the previously drilled wells are far apart, there is considerable uncertainty in predicting where and how the reservoir sandstone terminates updip.

Another empirical approach that may be successful is based simply on trend. Where early exploration in an area indicates that the sandstone bodies are elongate and aligned, an obvious step is to drill on trend. A good example is the Cretaceous "Gallup" or Tocito reservoirs of northwest New Mexico.

The spotty success of these simple methods forced consideration of more scientifically sophisticated techniques. Geologists reasoned that, if the origins of the sandstone bodies being sought were better understood, exploration would be more successful. A central idea was that recognition of the depositional environment, coupled with knowledge of paleoslope and distribution of enclosing facies, would be an effective approach to the location problem. Hence, much industry research on depositional models has been done in the past decade.

## Depositional Models

In Table 2, the exploration characteristics of environmental types of sandstone bodies encountered most in exploration are summarized. Because it is difficult to capture the essence of the conceptual model in a brief table of this kind, two or three useful references are cited for each environmental type.

How is the origin of a particular sandstone body determined? No one characteristic, or even any two in combination, is sufficient to permit identification or in some cases to narrow the possibilities significantly. Furthermore, for sandstones, in contrast to carbonate rocks, the kind of information available from cuttings—color, grain composition, and texture—has been of limited value when used alone. The characteristics best determined in cores or outcrops—especially sedimentary structures, nature of contacts, sequence, and relation to enclosing facies—are much more diagnostic.

Because the amount of information on depositional models that is decipherable from cuttings and logs is limited, effective use of them depends on how closely their characteristics can be related to more basic control from cores or outcrops. For example, a marked base and an upward decrease in grain size, characteristic of many valley fills, may be reflected on the SP curve by an abrupt excursion at the base and a gradual decrease upward. If this relation can be established in one or more wells in an area by core-log comparison, the character of the SP can be used as a secondary control in identifying and mapping the sandstone body.

As a second example, two different types of sandstones within a generally sandy interval may be distinguishable by a grain-size difference. In northern Colorado, the contact between the Horsetooth and Fort Collins Members of the Muddy Sandstone (transgressive deltaic sandstone versus regressive shoreline sandstone) was determined by binocular examination of grain size in cuttings after the relations were established by detailed outcrop study (MacKenzie, 1965). No consistent log difference was observable. It should be emphasized that this is purely a local characteristic.

If the paleogeographic setting and paleoslope, as well as the depositional model, are known, sandstone trends may be predictable. The clearest example is that of barrier-island sandstone bodies, which are usually parallel with the shoreline. Alluvial valley deposits trend generally parallel with the dip of the paleoslope, but major departures are common, and marine bars, even if elongate, tend to have diverse orientations.

Some implications of different sandstone depositional models to exploration and field development are illustrated in Figure 2. Although stratigraphic traps in most sandstone depositional types require local structure or updip bends related to regional dip, traps in isolated offshore-bar sandstone bodies require no special structural situation. Traps in porous marine sandstones developed by winnowing of the fines might be sought on local synchronous highs, but stratigraphic traps in sandstone beds deposited by turbidity currents would be sought on the edges of depositional lows.

### Halos

In the carbonate realm, the detection of debris beds in an exploratory well may indicate the presence of a nearby reef. In the sandstone realm, comparable proximity indicators are less common. However, some types of offshore bars are surrounded by facies halos in which clay content increases gradually outward. In the marine bars of the Willson Ranch field, Nebraska, for example (Exum and Harms, 1968), the gradient in clay content can be detected for a distance of 1–2 mi (1.6–3.2 km) beyond the field boundaries. These proximity indicators may be useful in locating low-clay (high-sand) areas (see "offshore bar," Fig. 2).

A similar example is related to the seaward margins of barrier islands. These sandstone bodies disappear seaward by becoming progressively thinner and finer grained until they merge imperceptibly into the enveloping shales. Recognition of this kind of seaward edge in two or more wells might provide a basis for determining the direction in which the porous and permeable part of the sandstone body lies.

In discontinuous sandstone units of the Rocky Mountains that have been partly flushed by meteoric waters, the salinity of formation waters—as indicated by normal or induction devices for example—may be a proximity indicator to oil accumulations. The hypothesis is that oil will be trapped only in the places protected from flushing. These relatively unswept parts should be characterized by higher formation-water salinities. Consequently, encountering waters with normal salinity in a formation otherwise known to be flushed fairly pervasively may be a clue to the proximity of oil. Although this technique has been widely discussed, I know of no demonstrable case where it has been applied successfully to oil finding.

### Differential Compaction

Wherever a sandstone body is replaced laterally by a shale section, some degree of differential compaction almost certainly will result (Mueller and Wanless, 1957). An example is shown in Figure 3. The effect of differential compaction normally persists upward in the section for a few hundred or more feet. This drape is reflected as structure in the younger beds and, in places, can be used to infer the presence of discontinuous sandstone bodies in a section deeper than that penetrated.

Rittenhouse (1961) illustrated the problem of restoring the cross section of an isolated sandstone body to its original shape. It is clear that, where differential compaction has been a significant factor, cross-sectional shape is an unreliable index of the depositional model. Truncation of older markers and onlap of younger markers are more useful criteria.

### Seismic Responses

There have been many attempts to prospect for stratigraphic traps in sandstone with the reflection seismograph, and the results have been disappointing. The principal problem has been that the wavelength of seismic energy returned to the surface is greater than the thickness of the sandstone bodies being sought. Most individual sandstone bodies are less than 100 ft (30 m) thick. Where such sandstone bodies are deeper than a few thousand feet, their lateral variations or terminations are seismically invisible.

A more general but still valuable goal is the detection of other stratigraphic information—such as sandstone-shale ratios and the thickness, continuity, and spacing of individual sandstone beds. By use of the concept of sedi-

Table 2. Summary of Characteris

| | | GENERAL LITHOLOGY | CHARACTERISTICS OF ENTIRE SEDIMENT BODY: THICKNESS (FEET) | SHAPE, HORIZONTAL DIMENSIONS | DISTRIBUTION, TREND | RELATIONSHIP TO ADJACENT OR ENCLOSING FACIES | CHARACTERISTICS C: LITHOLOGY, COMPOSITION, TEXTURE, FAUNA | BOUNDING CONTACTS | OV VE GRA CI |
|---|---|---|---|---|---|---|---|---|---|
| | SUBAERIAL MIGRATED DUNE SANDS | sands, no muds; homogeneous | 10 to > 1000 | elongate, or sheets up to 1000's of sq. miles in area | downwind from source of sand | commonly the end stage of a regressive sequence | well sorted sands; pebbles & clasts rare | variable | not sy |
| | ALLUVIAL SANDS | sands, muds, some gravels | usually 30-80; sometimes 200-300 | continuous bodies; usually ½ to 5 mi. wide, 10's to 100's of miles long | make large angles with shoreline trends | lower contacts erosional; lateral contacts erosional or indeterminate | pebbles and clasts common; proportion of mud variable | base erosional; top usually transitional | up di |
| DELTAIC DEPOSITS | DISTRIBUTARY CHANNEL FILLS | sands, muds | up to 200 | continuous sinuous bodies, usually < 1 mi. wide | | commonly enclosed in nonmarine or brackish muds | | | |
| | DELTA-FRONT SHEET SANDS | sands | 20-80 | sheets | | underlain by marine pro-delta muds; overlain by marsh muds | | | |
| | REWORKED TRANSGRESSIVE SANDS | sands | 1-40 | sheets | | underlain by or adjacent to deltaic deposits | well sorted; may contain coarse sand lag | both sharp | nc s |
| | REGRESSIVE SHORELINE SANDS (BARRIER-ISLAND SANDS) | sands; rare muds | 20-60 | elongate or sheets, up to miles wide, 10's of miles long | parallel to shoreline where elongate | transitional downward and seaward into muds, landward into lagoonal or deltaic deposits | well sorted; pebbles & clasts rare; marine fauna, if any | base transitional; top sharp | up in (b m co be |
| SHALLOW MARINE SANDS | OFFSHORE BARS | sands with mud partings | several to 10's | elliptical lenses, less than a few sq. miles in size | scattered; orientation variable | enclosed in and intertongues laterally with marine muds and silts | | sharp, or narrowly transitional | |
| | STRIKE-VALLEY SANDS | fine to coarse sands and muds; heterogeneous | 10-50 | elongate up to several miles wide, 10's of miles long | parallel to pre-unconformity paleo strike | fills erosional strike valleys; intertongues with marine muds seaward; onlaps landward | pebbles, clasts, glauconite, phosphate, marine fauna | variable | p s |
| DEEP-WATER SANDS | PROXIMAL TURBIDITES | interbedded sands, silts and muds | 100's to 1000's | fans or sheets up to 1000's of sq. miles in area | high flanks of deep basins near sand source | may be middle part of regressive sequence from deep to shallow-water deposits | graded bdg; displaced shallow-water fauna; proximal turbidites often with interbedded debris beds | | |
| | DISTAL TURBIDITES | | | | sumps of deep basins* | sands interbedded with deep-water muds | | | |

Table 2. Summary of Characteristics [of] Some Environmental Types of Sand Bodies

| [SED]IMENT BODY: RELATIONSHIP TO ADJACENT OR ENCLOSING FACIES | CHARACTERISTICS OF: LITHOLOGY, COMPOSITION, TEXTURE, FAUNA | BOUNDING CONTACTS | OVERAL[L] VERTIC[AL] GRAIN-[SIZE] CHAN[GE] | INDIVIDUAL VERTICAL SECTIONS — PRIMARY SEDIMENTARY STRUCTURES: STRATIFICATION | CROSS-STRATIFICATION: CONTACTS; SET THICKNESSES | CROSS-STRATIFICATION: NATURE OF LAMINAE | CROSS-STRATIFICATION: SHAPE OF SETS | RIPPLES | DEFORMATIONAL AND ORGANIC SEDIMENTARY STRUCTURES | MISCELLANEOUS REMARKS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|
| commonly the end stage of a regressive sequence | well sorted sands; pebbles & clasts rare | variable | not system[atic] | conspicuous high-angle cross bedding | erosional, horiz. or sloping; sets up to 10's of feet thick | lee dips 25°-34°; commonly tangential to lower boundary | tabular; sometimes enormous troughs | high indices; crests often parallel to dip of lee beds | slumps not uncommon; vertebrate tracks | | McKee (1966) |
| lower contacts erosional; lateral contacts erosional or indeterminate | pebbles and clasts common; proportion of mud variable | base erosional; top usually transitional | upwar[d] decrea[se] | many beds lenticular; abundant cross bedding | erosional, planar or concave up; usually ¼-2 feet thick | maximum dips usually 20°-25°, inclined or tangential to lower boundary | trough | short-crested; linguoid; microtrough in cross-section; abundant | slumps common; burrows uncommon | | Harms (1966) Hewitt & Morgan (1965) Fisk (1944) Potter (1967) |
| commonly enclosed in nonmarine or brackish muds | | | | | | | | | slumps, burrows not uncommon | | Frazier (1967) Brown (1969) |
| underlain by marine pro-delta muds; overlain by marsh muds | ← | | | similar to barrier sand bodies → | | | | | | | |
| underlain by or adjacent to deltaic deposits | well sorted; may contain coarse sand lag | both sharp | not system[atic] | high-angle cross bedding; orientation diverse | erosional, planar; ¼-2 feet thick | maximum dips 20°-25°; tangential to lower boundary | wedge or tabular | not conspicuous; microtroughs present | slumps, burrows uncommon | lateral facies changes may provide proximity indicators | Frazier (1967) MacKenzie (1965) |
| transitional downward and seaward into muds, landward into lagoonal or deltaic deposits | well sorted; pebbles & clasts rare; marine fauna, if any | base transitional; top sharp | upward increase (but mi[ddle] may have coarser beds) | upper & lower: subhorizontal stratification with low-angle truncations, exp. near base; sets < 1 foot thick | | | | most abundant near base; symm., long-crested | load structures & burrows common at base | | Bernard et al (1962) Weimer (1966) McCubbin & Brady (1969) |
| | | | | middle: high-angle cross bedding, ¼-2 feet thick, tangential laminae; cross-laminae dip obliquely shoreward; local scours | | | wedge or trough | uncommon | uncommon | | |
| enclosed in and intertongues laterally with marine muds and silts | | sharp, or narrowly transitional | | low-angle cross bedding | erosional, planar; ~1 ft. thick | most dips < 10°; laminae parallel to lower set boundary | wedge? | common; some symm., long-crested | burrows abundant only in marginal facies | gradual outward decrease in sand/clay may provide proximity indicator | Exum & Harms (1968) |
| fills erosional strike valleys; intertongues with marine muds seaward; onlaps landward | pebbles, clasts, glauconite, phosphate, marine fauna | variable | not system[atic] | tabular units with high-angle cross bedding dipping parallel to sand body elongation | erosional, planar; ¼-5 feet thick | max. dips 25°-30°; tangential to lower boundary | tabular; sets straight & continuous for 100's of feet | common locally, esp. at toes of x-sets; some are long-crested wave ripples | burrowing common | paleogeologic and paleotopographic maps effective in exploration | McCubbin (1969) |
| may be middle part of regressive sequence from deep to shallow-water deposits | graded bdg; displaced shallow-water fauna; proximal turbidites often with interbedded debris beds | | | parallel stratified or structureless, may have large mud-lined scours | trough-shaped sets found rarely | | | asymmetric ripples, both short and long-crested, found at tops of individual beds | burrows uncommon; bedding plane tracks and trails often present | cf. distal beds, proximal beds are thicker, coarser grained, less well graded, less regular, more deformed, and more porous and permeable | Walker (1966, 1967) |
| sands interbedded with deep-water muds | | | | [illegible] continuous beds, parallel or ripple stratified | | | | | | | |

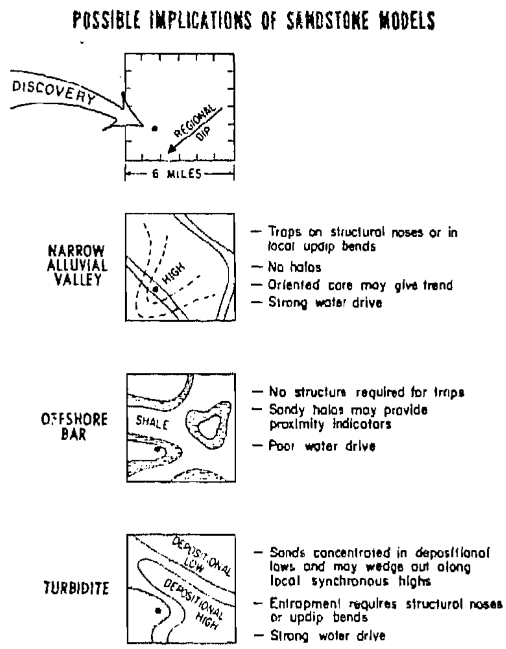


FIG. 2—Possible implications of selected sandstone depositional types to exploration and field development.

mentation models through sequences of hundreds of feet of strata, it may be possible to make the step from seismic field records to stratigraphic interpretations. Sedimentation models are not random stacks of various lithologies; rather, they commonly are organized systematically. The use of reflection seismic data for recognizing and deciphering these systematic stratigraphic relations in areas of sparse well control holds much promise (Harms, 1968).

### Field Development

Once oil has been discovered in a stratigraphic trap, efficient field development depends in part on the geologist's ability to predict size, shape, trend, and distribution of internal reservoir characteristics from the early well data. This is "the extension problem" (Potter, 1967).

Even where control is available in wells on a 40-acre or smaller spacing, depositional models have been found to have a major application in reservoir geology. Although well control may be very close, one well commonly cannot be correlated satisfactorily with the next, or the reservoir adequately characterized, in the absence of understanding of the depositional model. Even the spacing of the contours on an isopach map of a sandstone body depends on the model, and good contouring can contribute substantially to locating the margins of a reservoir beyond the points of dense control.

Reservoir geology is particularly important in successful application of enhanced oil-recovery techniques such as *in situ* combustion and miscible waterflooding. These technically sophisticated operations require large dollar investments for either expensive injections or fluids for injection. Unless the geology of the reservoir is exceptionally well established before the recovery program is formulated, total economic failure may be the result.

One common and important problem in field development is how to decipher the trend of a sandstone body from core observations. The approach assumes a known relation between the orientation of primary sedimentary structures and the trend. The relation probably is best established for alluvial sandstones. However, because of potentially large variability in current direction locally, it is usually important to measure the orientation of several tens of sets of cross-strata. In many other types of elongate sandstone bodies, the relation between trend and sedimentary structures is not reliably predictable. In barrier islands, for example, trough-shaped crossbedding reflects currents flowing obliquely landward (Reineck, 1963) at widely varying angles to the trend of the sandstone body.

Deciphering trend also assumes that a core in the subsurface can be oriented geographically. The best method is by inhole magnetic orientation of the core barrel when the core is cut. Another possibility[2] is to relate the remanent magnetization of the core to the paleomagnetic field prevailing when the sands were deposited. The paleomagnetic method is useful only for sites relatively near the paleomagnetic equator, and successful application is rare.

Hewitt and Morgan (1965) described the reservoir characteristics of a Pennsylvanian alluvial sandstone which forms the reservoir at the Fry *in situ*-combustion site in the Illinois

[2] Much of the logging company literature notwithstanding, our experience in comparing cores with dipmeter surveys suggests that cross-stratification is usually not detectable by dipmeter measurements. The reason is that few cross-strata within sandstones are marked by clay partings or other mineralogic (or resistivity) contrasts (see also Jizba *et al.*, 1964).

Cores with dipping beds can, of course, be oriented geographically by reference either to known regional dip or to a dipmeter survey.

[For a more detailed discussion of use of dipmeter data, see paper by Jageler and Matuszak (this volume). *Editor*]

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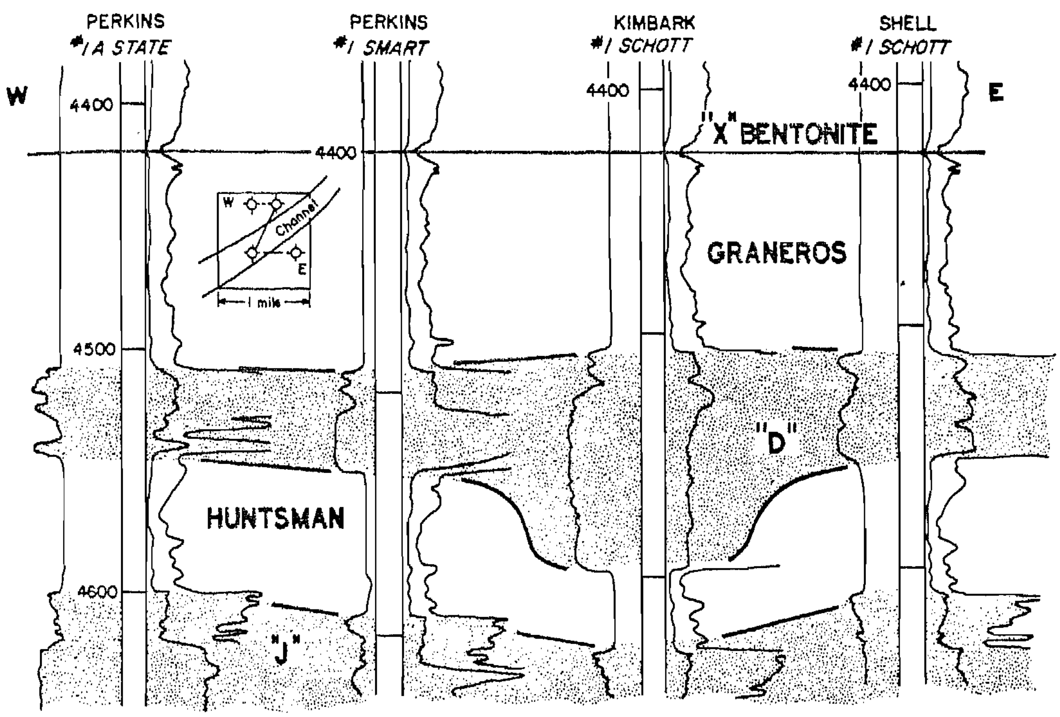



FIG. 3—Differential compaction around Cretaceous "D" alluvial channel sandstone in Sec. 21, T6N, R53W, Logan County, Colorado.

basin. Among the interesting characteristics of the reservoir is the relation of directional horizontal permeability to the current direction of the depositing river. In sandstones with both small-scale and large-scale trough cross-stratification, the horizontal permeability at right angles to the current direction is between 85 and 95 percent of that parallel with the current direction. Montadert (1963) applied knowledge of sedimentary structures gained on outcrop to the establishment of preferred permeability directions within the Hassi-Messaoud field of Algeria.

## Fairway Delineation

The easiest and most common approach to the question of where exploration should be concentrated is to relate belts of stratigraphic-trap oil occurrence to one or more easily measured stratigraphic parameters. In extension of a fairway within a developing basin, the parameters can be derived empirically from within the area already productive. In less explored areas, they can be sought by comparing oil occurrence with stratigraphic factors in mature basins believed to be similar.

Among the most common of these parameters are ratios of sandstone to shale. In many areas the occurrence of oil tends to be within a belt in which the ratio of sandstone to shale is in the value range known to be optimum for the area (Dickey and Rohn, 1955). On the Gulf Coast, this phenomenon is referred to the "sand-breakup" in a transition from massive sandstone landward to shale seaward.

The next step is to try to reconstruct the paleogeography. This step commonly involves no more than delineation of the broad areas of marine and nonmarine deposition. The more prospective areas generally lie in the belt where marine and nonmarine deposits intertongue. From these general paleogeographic reconstructions, much more detailed ones can be made if appropriate rock materials are available for examination and interpretation. Fisher and McGowen (1969) related oil and gas productive trends in the lower Wilcox Group (Eocene) of the Texas Gulf Coast to many specific depositional environments.

In fairway delineation, undue emphasis has been placed on the depositional environment as the controlling factor. Other important factors

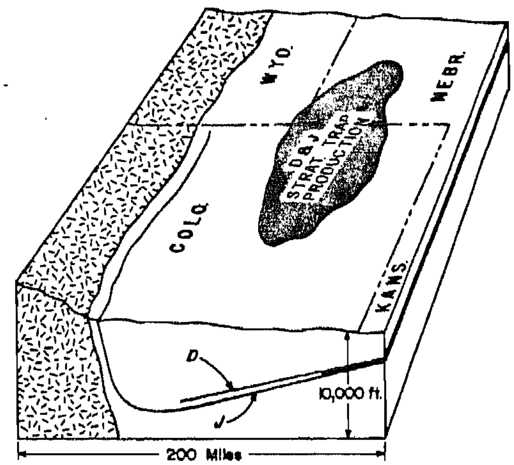



FIG. 4—Fairway of Cretaceous stratigraphic production in Denver basin of eastern Colorado and western Nebraska.

are the postdepositional history of the sediments, adequacy and proximity of source rocks, and the effects of formation-water movement and structural tilting and deformation.

The importance of formation-water fluid potentials (hydrodynamics) in fairway delineation was stressed by Hill *et al.* (1961). They argued that the most favorable sites for belts of productive stratigraphic traps were gentle flanks of sedimentary basins characterized by downdip flow (or downdip potential gradients) through discontinuous sandstone bodies. In such situations, the capacity of updip shale barriers forming the traps would be augmented by the potential gradient.*

An example of a productive stratigraphic-trap trend probably determined by both facies change and favorable potential gradients is the Middle Jurassic Shaunavon trend of southwest Saskatchewan (Christopher, 1964). In this area, 400 million bbl of ultimately recoverable reserves are contained in only 20 fields where oil is trapped stratigraphically in sandstones (Carlson, 1968). Two of these fields, Dollard and Bone Creek-Instow, have reserves of more than 70 million bbl each. All the fields are in shelf deposits. The narrow shelf trends north-northeast and dips eastward; it is bounded on the west by lagoonal deposits and on the east by basinal shales and carbonate rocks. The sandstone reservoirs are marine bars and tidal-channel fills partly enclosed in argillaceous facies. Continuity of the sandstones updip beyond the pools (westward) and the information on formation pressures suggest that eastward decrease in fluid potential has been important in entrapment.

Some caution on the overemphasis of any one technique is certainly warranted. For example, although there was much study of hydrodynamics in the late 1950s and early 1960s, I know of no well-documented case in which its application has led to a significant discovery.

### Denver Basin Fairway

The problems of fairway delineation can be illustrated by the production from stratigraphic traps in the Cretaceous on the east flank of the Denver basin (Fig. 4). The initial discovery was made by Marathon Oil Company in western Nebraska in 1949. From that time until the mid-1960s, about 17,000 wells were drilled. This exploration resulted in several hundred fields with a total of about 800 million bbl of ultimately recoverable reserves. Exploration was reactivated in 1970, particularly in the area just east of Denver.

The oil accumulations are in discontinuous sandstone bodies, localized on subtle noses, on the gently westward-dipping east flank of the Denver basin. Structural entrapment is significant only in the northeastern part of the fairway.

Production is from two zones—the "D" and "J" sandstones. Each has an average thickness of several tens of feet and consists of a wide variety of shallow-water marine to nonmarine units, generally lenticular, and complexly arranged in both plan and cross-sectional views. The "D" sandstones were derived entirely from the Canadian shield on the east; they pinch out westward at a depth of about 6,500 ft (1,980 m) in the basin. The "J" sandstones were derived from the Cordilleran region on the west, as well as the Canadian shield; they persist over the entire basin. Alluvial, offshore-bar, and other environmental types of sandstones form the reservoirs.

Even though the "D" and "J" sandstones are everywhere separated by several tens of feet of unfractured shale, the fairway of "D" sandstone production nearly coincides with the fairway of "J" sandstone production. Why the fairways overlap and why they are located where they are is not known. Because a similar assemblage of depositional units persists far east of the fairway in both the "D" and "J," and west of it in the "J," the answer does not lie wholly in considerations of depositional environment. Other important factors must be involved. Hydrodynamics may be one of them. Gradients

* Dickey and Hunt (this volume) discuss the theory of formation-water fluid potentials; they conclude that downdip and updip flows are theoretically possible but unlikely to occur commonly in nature. *Editor*

are low in the fairway compared to those in the "J" sandstone farther west; however, significant downdip gradients cannot be demonstrated in the fairway.

As depth of burial increases west of the fairway in the Denver basin sandstones tend to become more tightly cemented—thus less porous. The interbedded shales become more fractured. This deterioration in quality of both reservoir and sealing beds may be significant to the western productive limits of the "J" sandstone.

On the east side of the fairway, burial of the source shales may not have been sufficient to allow primary migration. Alternatively, because the sandstones in both the "D" and "J" become thicker, more permeable, and more continuous eastward—with fewer updip shale barriers—oil once generated may have migrated eastward, escaped to the surface, and been dissipated.

The foregoing is an illustration of the complexity of the problem of fairway delineation, even in a mature and geologically well-known area. Further understanding will come probably from research on postdepositional factors rather than from better definition of the sedimentary environments.

Some aspects of paleogeographic reconstruction, particularly in relation to transgression and regression, may provide more help in fairway delineation than has been available in the past.

### Overall Transgression Versus Overall Regression

Thick sequences of broadly intertonguing marine and nonmarine beds contain many potential stratigraphic traps, particularly where sandstone bodies are associated with the shoreline. An appropriate model of this type of deposition is the Upper Cretaceous of Wyoming, which is a thick sequence of nonmarine beds and shoreline marine sandstones intertonguing eastward with marine shales. Major source areas on the west supplied sediments to the broad coastal plains along the west side of the seaway. The shoreline migrated back and forth throughout most of Late Cretaceous time, resulting in the intertonguing relations. Exploration is a matter of dividing the sequence into time-parallel zones as thin as possible, and attempting to map the paleogeography, especially the strandline, for each zone.

Periods of overall regression are characterized by a seaward retreat of the various depositional environments. This seaward retreat usually is marked by abundant sediment supply and active seaward-building deltas with associated delta-front sand bodies. In contrast, during periods of overall transgression, the depositional environments shift landward, and because of rising base level the rate of sediment supply is relatively low. Sands are supplied by marine reworking of older deltaic deposits or by longshore transport from local river mouths along the shoreline. Barrier islands with associated landward lagoons are a common development. (The word "overall" is emphasized because, clearly, the barrier islands themselves formed by seaward progradation during episodes of stillstand or minor regression during the overall transgression.)

In parts of the Rocky Mountain area where regional dip of the Cretaceous is eastward,[3] the impact of these considerations on stratigraphic-trap exploration is as follows (D. G. McCubbin, personal commun.). During periods of overall regression, shoreline sand bodies, if present, may be replaced updip by deltaic deposits (Fig. 5). These deltaic deposits, because of their many associated types of sands—particularly distributary-channel sands—probably would be relatively poor barriers to updip migration.

In contrast, during periods of overall transgression, the shoreline sand bodies would be replaced updip by sand-poor lagoonal muds which, when compacted, would be relatively good barriers to updip migration of oil. Furthermore, the sands would be overlain by marine shales, which should be effective barriers.

In applying this concept to stratigraphic-trap fairway delineation in exploration, emphasis would be placed on finding ancient shorelines in interdeltaic areas, especially those of periods of overall transgression. It is not a coincidence that the only significant stratigraphic-trap oil discovery in the many Upper Cretaceous shoreline sandstones of Wyoming (Patrick Draw) is in an overall transgressive rock sequence (Weimer, 1966; McCubbin and Brady, 1969).

Other examples of stratigraphic traps in shoreline sandstones resulting from overall transgressive sedimentation are the basal Pennsylvanian[4] Morrowan sandstones of northwest Oklahoma (Busch, 1959).

[3] In areas of west dip, because of gradual eastward (offshore) decrease in thickness and permeability of shoreline sandstones, and ultimate gradation into marine shales, stratigraphic traps would not be expected because reservoir and barrier beds would not be close enough together.

[4] D. C. Swanson, in a preceding paper in this volume, presents evidence that the Morrowan clastic units are not transgressive, but are facies equivalents of the Chesteran carbonate shelf deposits. *Editor*

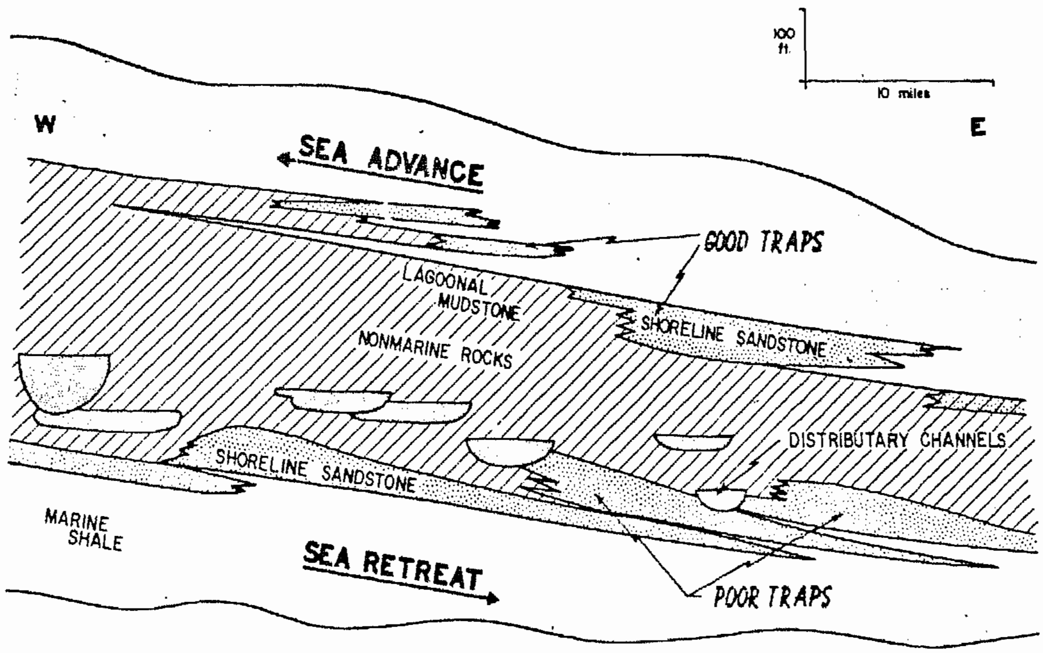



FIG. 5—One schematic cycle in Rocky Mountain Upper Cretaceous showing deltaic distributary channels landward and updip from shoreline sandstones deposited during overall regression (below), and lagoonal mudstones landward and updip from shoreline sandstones deposited during overall transgression (above).

### Why Are Few Stratigraphic Traps Found in the Gulf Coast?

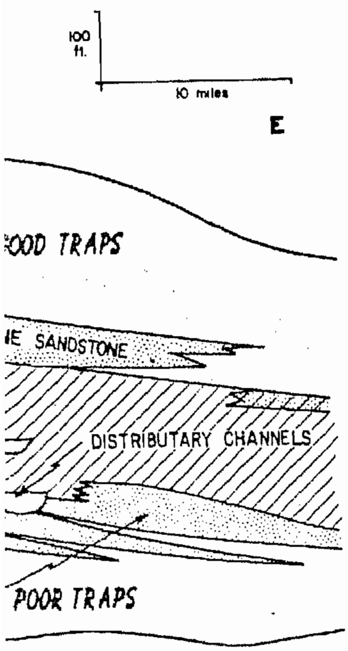
In light of the foregoing discussion, and in view of the abundant transgressions and regressions and known heterogeneity of the onshore Gulf Coast Tertiary section, the scarcity of recognized stratigraphic traps there is puzzling. (Although common in the Wilcox and Vicksburg Groups, stratigraphic traps are scarce in the post-Eocene part of the section.) The most probable explanation is that early-formed structures were ubiquitous in the zone of oil generation and migration. In this particular zone of intertonguing sandstones and shales, the following conditions prevailed: (1) The shales were buried deeply enough for oil to have been generated. (2) The sandstones interbedded with the shales provided both the avenues of migration and the reservoirs. (3) Contemporaneous structures formed by gravitational sliding and/or piercement tended to be concentrated there and trapped most of the migrating oil. Even though the distribution of oil might be governed partly by lateral changes from sandstone to shale, the traps would be called "structural."

In contrast, in shallow areas where there are updip pinchouts, as in the updip Frio of coastal Texas, the shales interbedded with the sandstones may not have acted as sources because they were not buried deeply enough. Oil generated farther downdip was trapped mainly in downdip traps.

An alternate explanation assumes there are relatively few updip changes from reservoir to barrier lithology because potential barriers are leaky owing to widespread, deltaic, distributary-channel sandstones located shoreward. This explanation seems unlikely, however, because the distribution of oil on many structures is definitely stratigraphically controlled; thus, the presence of locally effective barriers is implied.

### Sandstones Above Unconformities

Although the importance of angular unconformities in the geologic record long has been recognized (Levorsen, 1954), the abundance and importance of stratigraphic breaks with no angular discordance have not always been appreciated. However, increasing knowledge of stratigraphy indicates that disconformities are a common part of most stratigraphic sequences. Some disconformities are related to local epeirogenic movements; some appear to be of continental or intercontinental extent, suggesting eustatic changes in sea level. The waxing and

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waning of midocean rises (Menard, 1964) provides one explanation for greater frequency of eustatic movements in the geologic record than previously had been supposed.

As late as the early 1950s, for example, the Cretaceous of the western interior seaway was widely regarded as a continuous sequence with relatively few breaks in the stratigraphic record. That concept is no longer valid. Many unconformities and/or disconformities are present.

Waagé (1955) recognized a widespread Early Cretaceous transgressive disconformity in the lower part of the Dakota Group in the northern Front Range foothills of Colorado. What is probably the same surface (MacKenzie, 1965) subsequently was recognized in the Black Hills (Waagé, 1959) and in western Colorado (McCubbin, 1961). In northwest New Mexico, Dane (1960) recognized a widespread erosional surface between Carlile rock (Turonian) and lower Niobrara (Coniacian) rocks. On the basis of faunal evidence by Eicher (1960) and Ellis (1963), as well as physical evidence by Baker (1962), Harms (1966), and MacKenzie (1965), at least one and possibly several erosional surfaces of intra-Albian age are recognized within the Muddy sandstones. The reservoir of the Bell Creek field is directly above the faunal break discussed by Eicher and Ellis. On the basis of detailed ammonite zonation, Gill and Cobban (1966) have found a previously unrecognized unconformity of late Campanian age in western Wyoming. Apparently, several thousand feet of sediment has been eroded locally.

Where angular discordances are involved, the implication to petroleum exploration is clear enough: either pre-unconformity stratigraphic traps or pre-unconformity anticlines not reflected in the overlying beds are possible exploration targets. However, I believe emphasis should be placed on the importance of erosional surfaces—whether angular unconformities or disconformities—in determining the stratigraphic-trap possibilities in the directly overlying transgressive sandstones.

The distribution of sandstones above the surface of unconformity is determined in part by the paleotopography of the surface. In some situations there is a strong tendency for the sandstones to be concentrated in valleys or other lows on the surface. Spooner (1964) cited good examples from the basal Upper Cretaceous Tuscaloosa sandstones of east-central Louisiana. In other places, sandstones may be concentrated over the locally steeper parts of an erosional surface. Where the slopes are slightly steeper, the rate of transgression may have slowed, thus providing adequate time for the accumulation and winnowing of discrete reservoir sandstone bodies.

One approach to predicting the probable distribution of transgressive sandstone bodies overlying an unconformity is the application of quantitative aspects of geomorphology (Horton, 1945; Martin, 1966). These relate to average stream length, average stream spacing, and ratio of length between first- and second-order streams. The application of these quantitative concepts to paleosurfaces allows a general determination of the number of tributaries, length of streams, and channel slope.

An excellent example of oil trapped in sandstones whose distribution was controlled by the underlying erosional surface is the Cretaceous sandstone reservoirs of the San Juan basin in northwest New Mexico (McCubbin, 1969). These sandstones produce from stratigraphically controlled oil accumulations in marine strike-valley sandstones (a term coined by Busch, 1959) deposited during a transgression over the pre-Niobrara erosion surface (Fig. 6). Individual sandstone bodies are localized on the seaward side of cuesta faces formed by the outcrop of relatively resistant beds in the folded and truncated pre-Niobrara sequence. Successively younger sandstones in the overstepping sequence extend farther in the direction of transgression. The sands, transported parallel with the shoreline, were deposited in significant thicknesses where the advance of the sea was slowed by the increase in slope associated with the ridges.

The paleotopography of the erosion surface consisted of northwest-trending cuesta-like ridges and intervening valleys; the steeper slopes faced northeast. Local relief was more than 100 ft (30 m). Individual sandstone bodies are elongate parallel with the ridges and valleys on the erosion surface, and with the direction of sand transport. They thin abruptly to the southwest by onlap against the erosion surface, and thin more gradually in the opposite direction, largely by facies change to shale. Preunconformity shales and sandstones provide part of the barrier to updip migration of oil and gas.

The paleotopography of the erosion surface is obviously important in evaluating potential stratigraphic traps and in predicting the geometry of the reservoirs. The paleotopography is obtained from several kinds of maps. One is an isopach map of the interval between the uncon-

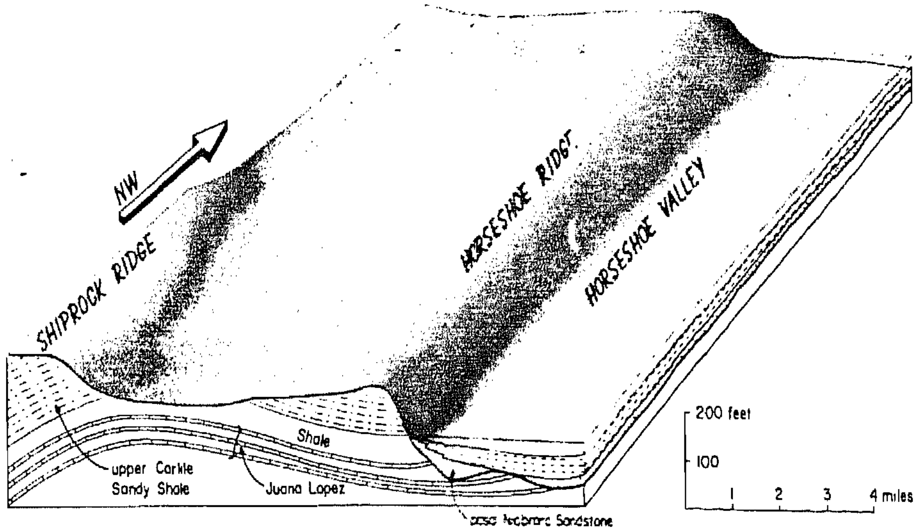



FIG. 6—Setting of basal Niobrara (Upper Cretaceous) strike-valley sandstone, northwest New Mexico (after McCubbin, 1969).

formity and some widespread, originally horizontal, marker above it. Corrections for differential compaction may be needed. However, since interpolation of patterns between control points is difficult, the isopach map should be supplemented by a paleostructural map. Structure at the approximate time the unconformity developed is reflected by an isopach map of an interval bounded by markers directly above and below the unconformity. The two isopach maps considered together make possible the construction of accurate paleogeologic and paleotopographic maps which aid in prediction of the trend and distribution of ridges and valleys, and hence strike-valley sandstones.

Strike-valley sandstones may be more common than presently recognized. The possibility of their existence should be considered wherever marine deposits directly overlie a tilted and truncated sequence of alternating resistant and nonresistant strata.

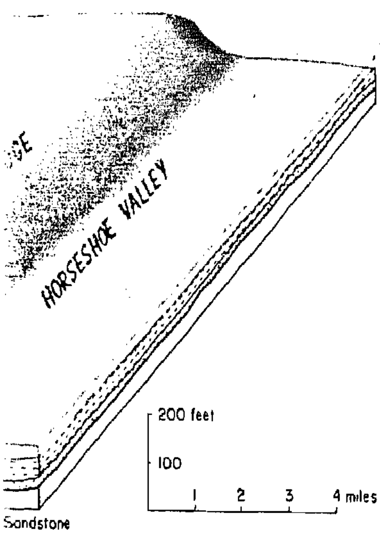
Although the preceding discussion has dealt only with sandstones overlying erosional surfaces cut subaerially, Yeats (1965) has documented an example in which the topography of a submarine unconformity controlled the distribution of overlying oil-bearing turbidites.

## Effective Use of Stratigraphic Controls in Exploration

From this review, it should be apparent that any one type of stratigraphic control is inadequate for an effective exploration program for stratigraphic traps in detrital rocks. Although, for any given subsurface section, a core is commonly the most useful source of data, core control nearly always is spaced too widely to be used alone. However, logs and cuttings, although generally providing closer control, are less useful for many kinds of interpretations. The soluion to this apparent dilemma is to integrate, so far as possible, the various types of control. The key to successful interpretation is to establish, within each area of relatively homogeneous stratigraphy, correlations between characteristics as determined by the different types of control available.

With detailed core or outcrop study as a starting point, it is commonly possible to subdivide an interval into correlatable stratigraphic units. The next step is to determine how each of the units can be recognized and correlated, using the more densely distributed but less definitive types of logs in common use in the area. The logs then become satisfactory substitutes for cores. (At this stage, a comprehensive well-data system in which digitized logs are an integral part may be meshed with appropriate programs to yield maps useful in exploration.)

In the same way, a particular lithologic unit, with detailed characteristics established by core examination, may be recognizable in cuttings by a diagnostic color, texture, or mineralogy. The examination of cuttings should be tailored to the specific job. By recording only those particular characteristics that serve to distinguish

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members recognized in the area and zone being studied, sample examination time is greatly shortened and the value of the resulting sample log is greatly increased.

If this approach is used, the reader may ask how the significant data can be recognized. There are, of course, no pat answers; but adherence to one general rule is essential: *interpretation should proceed apace with description.* The tendency is strong to develop a routine that stresses uncritical description and defers interpretation until all the cores or sets of cuttings have been described. To a great extent, one sees only what he is looking for and, unless an attempt is made to interpret the rocks as they are being described, much significant information will be overlooked. The adoption of multiple working hypotheses is even better. Although it is commonly necessary or expedient to follow the lines of inquiry suggested by one hypothesis, evaluation of the observations according to several hypotheses tends to bring into focus the differentiating criteria.

## Research Needs

### More and Better Models

Although our knowledge of depositional models has grown dramatically in the past decade, there is still a need for a wider spectrum and more detailed information for use in exploration. A particularly large gap is that of the distinguishing characteristics of sandstone bodies deposited in shallow-marine environments offshore. In the range of environmental types from subaerial dunes to deep-water sands, the shallow-marine environments are the least well known.

### Offshore

As exploration emphasis shifts offshore, there is a growing need for stratigraphic predictions in the absence of nearby outcrops and continuous cores. Ways must be found to make more effective use of cuttings, logs, and surface geophysical information to predict the distribution of reservoir sandstones, stratigraphic traps, and favorable source-reservoir relations. The application of this exploration technique is most advanced in the Gulf Coast offshore, where the base of the reflection curtain visible on common-depth-point seismic-record sections is being used to map the base of potential reservoir sandstones.

### Seismic Energy of Higher Frequency

A third research need is the successful return of higher frequency seismic energy from greater depths and the interpretation of the resulting data. Since primary stratigraphic traps are related to lateral changes in relatively thin intervals (usually less than 100 ft or 30 m), the higher the frequency of seismic energy returned, the more opportunity there will be to detect lateral seismic anomalies relating to time or character that can be interpreted in terms of stratigraphic traps.

### Giants Versus Dwarfs

A fourth need is to determine whether the few large primary stratigraphic traps have unique and predictable characteristics as compared with small traps. Are the large ones large because of size of the sandstone body, greater porosity, a more prolific source, a larger trap, a more effective updip seal, or some combination of these factors? The answers might assist in diverting exploratory effort from the small, scarcely economic traps to the more profitable ones.

Many writers have called attention to the common proximity of oil occurrence to unconformities. Of the giant primary traps listed in Table 1, Bell Creek is underlain by a disconformity, and Cut Bank and probably Burbank (D. R. Baker, personal commun., 1969) are underlain by erosional surfaces. Giant stratigraphic traps beneath unconformities are well documented.

Consequently, in a quest for giant fields, more attention to finding subtle unconformities and disconformities and to mapping their paleotopography and paleogeography would be a useful exploration approach.

## Future Exploration for Primary Stratigraphic Traps in Sandstone

In areas where leasing and drilling costs are low, primary stratigraphic traps in sandstone-shale sequences are still worthwhile exploratory objectives, particularly for independents. In addition, a growing knowledge and appreciation of the habitats of such traps hopefully will increase the ratio of wildcat successes to failures.

As this book testifies, however, cases are rare in which primary stratigraphic traps in sandstone have been found where predicted. Moreover, major accumulations of oil in such traps are few—worldwide. Consequently, a large-scale, major-company search for them specifically would not seem justified. Such an exploratory effort would be warranted only with a vastly improved technology.

Whether or not that degree of improvement takes place, there is a much better alternative which can be applied now. Our increasingly sophisticated understanding of stratigraphy, depositional models, and diagenesis should be applied to finding not only stratigraphic traps, but all kinds of traps. Rather than focusing narrowly on primary traps, we should apply our knowledge to the problem of predicting fairways of favorable source, reservoir, and trap relations. In these fairways, we can concentrate exploration for anticlinal, fault, and pre-unconformity traps, as well as for the primary ones discussed in this paper.

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